WenZhong Gao[1,*], Ashwani Kumar[2],

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Evaluation of secure Bilateral Transactions with Distributed Generation in Hybrid Electricity Markets

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Evaluation of secure bilateral transactions is one of the important functions of system operator to maintain power system security for better planning and operation in open access competitive restructured electricity markets. With integration of distributed generation resources, the security issue of bilateral coordinated markets has gained further attention as distributed generation sources can enter into bilateral contracts with distribution companies. This paper proposes a new method for secure bilateral transactions determination in the presence of distributed generation share in bilateral coordinated electricity markets. The secure bilateral transactions have been determined with different share of distributed generation along with the conventional generators. The pattern of secure bilateral transactions for conventional generation, distributed generation, generation share for bilateral demand, and demand pattern have been obtained for pool plus bilateral market model. The proposed technique has been applied on IEEE 24-bus reliability test system (RTS).

Keywords: Distributed generation, secure transaction matrix, transaction matrix pattern, non-linear programming, AC distribution factors.

1. Introduction

In an open access bilateral/multilateral environment, the power transactions are expected to increase among the trading entities, which can threaten the system security and reliability. These bilateral transactions can affect the loading pattern of transmission corridors with different generation schedule. This may require the System Operator (SO) to reschedule the system generating units in order to accommodate these transactions. Therefore, these transactions should be evaluated ahead of their scheduling and should ensure their feasibility and security for better planning and management of competitive electricity markets.

Authors in [1] described a method for evaluating potential non-firm contracts feasibility with respect to system operating constraints and operating costs. However, the method did not discuss the feasibility of simultaneous transmission contracts. The impact of non-firm transactions on reliability and operating cost of power systems was proposed in [2]; however, it cannot handle the case with large number of bilateral transactions. Available Transfer Capability (ATC) based assessment for the feasibility of simultaneous transactions has been proposed in [3]. A mathematical framework for the analysis and management of power transactions ensuring system security has been presented in [4].

Cheng et al. [5] proposed determination of bilateral contract model through transaction matrix defined in [4] using DC load flow based approach addressing various operational and planning problems. Same authors proposed probabilistic approach to analyze multiple random simultaneous transactions on the basis of system security utilizing Monte Carlo simulations [6]. However, the methodology proposed in [5, 6] was based on DC

* Corresponding author: Ashwani Kumar, Department of Electrical Engineering, National Institute of Technology, Kurukshetra, India, E-mail: ashwa_ks@yahoo.co.in

1 faculty of Electrical Engineering, University of Denver, Denver, USA

2 Faculty of Electrical Engineering, National Institute of Technology, Kurukshetra, India

distribution factors and DC load flow approach and was applied for pure bilateral market model. A transaction assessment method for allocating transmission services to individual transactions using a simple AC power flow based procedure was proposed in [7]. An optimization procedure that assures the transmission security with minimum corrections in contractual transactions was proposed in [8]. Transaction analysis using game theory was proposed in [9]. Li and Liu proposed stability analysis of the strategic transaction in a deregulated environment [10]. The concept of feasible and secure transactions, which estimates the adequacy of a deregulated network and corresponding remedial measures required to improve this adequacy such as using FACTS controllers were examined in [11]. A secure bilateral transaction matrix determination for hybrid electricity markets based on DC and AC load flow approach using DC and AC distribution factors was proposed in [12-15]. It was observed that AC distribution factors give more accurate results than the DC distribution factors based approach since AC distribution factors quantify the change in operating conditions of a system with any change in operating parameters. Parsa et al. proposed optimal rescheduling of power transactions matrix in multilateral environment obtained through adjustment of weighing factors of cost function [16]. Evaluations of bilateral transactions considering optimal dispatch and transmission pricing have been proposed in [17].

Since electricity market are undergoing tremendous transformation, the factors like more price volatility in the market, ageing infrastructure, and changing regulatory environments are demanding users and electric utilities to harness benefits of distributed generation [18-19]. Distributed generation (DG) integration with the conventional generators is expected to play important role in future competitive markets due to their economic viability and sustainability. Based on the study of Electric Power Research Institute (EPRI) and Natural Gas Foundation, 30% of power generation share will be of distributed generation [20]. The DG technologies may comprise small gas turbines, micro-turbines, fuel cells, wind and solar energy and can be connected in an isolated or an integrated way in the existing power system network. The planning and operational issues relating to policy of integration of DGs into power system and their impacts in steady state power system operation, assessment of several factors such as the number and the capacity of units, best possible location in the network, and impact of DG on the system operation characteristics such as system losses, voltage profile, stability and reliability issues, contingency analysis, protection coordination as well as dynamic behavior were discussed in [21-23]. Thus, the determination of secure bilateral transactions in the presence of distributed generation share in open access environment requires attention for better future planning and operation of competitive markets.

In this paper, a new approach to determine secure bilateral transactions with distributed generation available in the network has been proposed for pool plus bilateral coordinated electricity markets. An objective function minimizing deviations from the proposed transactions have been formulated in the presence of conventional and distributed generators in a system. Bilateral transactions model have been modified with distributed generators along with conventional generators. Pattern of secure bilateral transactions for conventional generators and distributed generators have been determined. The generation schedule for conventional and distributed generation share have been obtained for different cases of bilateral share with conventional and distributed generator share in the network.

The load share has also been obtained for different cases of bilateral share with conventional and distributed generators. A non-linear programming (NLP) approach has been utilized for secure transactions determination using GAMS 21.3 CONOPT solver [24]. MATLAB and GAMS interfacing has been used for modeling the system. The parameters like bus admittance matrix, data elements etc. required for computation are calculated in MATLAB environment and transferred to an optimization model in GAMS environment for solving a complex problem [25]. The proposed approach has been applied to IEEE 24-bus system Reliability Test System (RTS) [26].

2. Notation

The notation used throughout the paper is stated below.

Indexes:

n_g and n_d	number of generators and loads
sb_{CG}, bb_{CG},	seller bus and buyer bus for conventional generators

Constants:

sb_{DG}, bb_{DG}	seller bus and buyer bus for distributed generator
P_i Q_i	real and reactive power injection at bus-*i*
P_{gi}, Q_{gi} P_{di}, Q_{di}	real and reactive power generation and loads at bus-*i*
V_i δ_i	Voltage and ange at bus-*i*
$V_i^{\min}, V_i^{\max}$	upper and lower voltage magnitude limi]
$\delta_i^{\min}, \delta_i^{\max}$	upper and lower angle limit]
$Y_{ij}=G_{ij}+B_{ij}$	*i-j*th element of Y-bus matrix
$P_{gi}^{\min}, P_{gi}^{\max}$	minimum and maximum real power generation limit
$Q_{gi}^{\min}, Q_{gi}^{\max}$	minimum and maximum reactive power generation limit
P_{ij}, Q_{ij}	real power flow and reactive power flow in a line-*ij*
S_{ij}	MVA flow in each line-*ij*
$S_{ij}^{\max}$	MVA line flow limit
$\boldsymbol{P_g}$ and $\boldsymbol{P_d}$	vector of total generation and total load
$\boldsymbol{P_{gp}}$ and $\boldsymbol{P_{gb}}$	vector of pool generation and bilateral generation
$\boldsymbol{P_{dp}}$ and $\boldsymbol{P_{db}}$	ector of pool and bilateral demand with conventional and distributed generators
$\boldsymbol{P_{gb}^{CG}}$, $\boldsymbol{P_{db}^{CG}}$	vector of bilateral generation and demand with conventional generators
$\boldsymbol{P_{gb}^{DG}}$, $\boldsymbol{P_{db}^{DG}}$	vector of bilateral generation and demand with distributed generators
$\boldsymbol{P_{fp}}$ and $\boldsymbol{P_{fb}}$	vector of line flows due to the pool and bilateral transactions
$\boldsymbol{P_{fb}}$ $=\boldsymbol{P_{fb}^{CG}}+\boldsymbol{P_{fb}^{DG}}$)	vector of sum of power flow due to bilateral transactions with conventional and distributed generators
$\boldsymbol{P_f}$ (= $\mathbf{P_{fp}}$ + $\mathbf{P_{fb}}$)	vector of sum of line flows due to the pool and bilateral transactions
ACDF	AC load flow based distribution factors
T_{ij}^{CG} and T_{ijCG}^{o}	secure and proposed bilateral transactions with conventional generators

T_{ij}^{DG} and T_{ijDG}^{0}	secure and proposed bilateral transactions with distributed generators
T_{ijCG}^{0}, T_{ijDG}^{0}	proposed bilateral transactions with conventional and distributed generators
t_{ij}^{max}	maximum transaction amount
b_{ij}	weighing factor indicating the importance of a particular transaction
$\boldsymbol{x}$	state vector of variables V, δ
$\boldsymbol{u}$	control parameters, P_{gi}, Q_{gi}, P_{gb}, P_{gp}, $\boldsymbol{P_{gb}^{CG}}$, $\boldsymbol{P_{gb}^{DG}}$
$\boldsymbol{p}$	fixed parameters P_{d}, $\boldsymbol{P_{db}}$, $\boldsymbol{P_{dp}}$, $\boldsymbol{P_{db}^{CG}}$, $\boldsymbol{P_{db}^{DG}}$, Q_{d}, T_{ijCG}^{0}, T_{ijDG}^{0}

3. A Lossless Bilateral Contract Model: Transaction Matrix with Distributed Generation

The bilateral contract model used in this paper is basically a subset of the full transaction matrix proposed in [4]. In its general form, the transaction matrix T as given in (1) is a collection of all possible transactions between Generation Companies GenCos (G), Distribution Companies DisComs (D), and any other trading Entities (E) such as the marketers and the brokers.

$$T = \begin{bmatrix} GG & GD & GE \\ DG & DD & DE \\ EG & ED & EE \end{bmatrix} \tag{1}$$

In present paper, it is assumed that there are activities restricted to the GenCos (G) and DisComs (D). The suppliers called Generation Companies (GenCos) as a seller bus (*sb*) and the customers as Distribution Companies (DisCom) called buyer bus (*bb*) are entering into bilateral contracts. In this work, the distributed generators have also been considered in the network with assumed different share of bilateral transactions with the buyer buses. Neglecting transmission losses, the transaction matrix can be simplified with conventional and distributed generation as:

$$T \equiv \begin{bmatrix} GD_{CG} & 0 \\ 0 & GD_{DG} \end{bmatrix} \tag{2}$$

GD_{CG} and GD_{DG} refer the bilateral transactions between GenCos and DisCom corresponding to conventional generators and distributed generators. Each element of T, namely t_{ij}, represents a bilateral contract between a supplier (P_{gi}) of row i with a consumer (P_{dj}) of column j. Furthermore, the sum of row i represents the total power produced by generator i and the sum of column j represents the total power consumed at load j. The transaction matrix T can now be modified with distributed generators which are also participating in bilateral contracts. The new modified matrix of transactions having transactions with conventional and distributed generators can be written as:

$$T \equiv \begin{bmatrix} t_{1,1} & \cdots & t_{1,nd} & 0 & \cdots & 0 \\ t_{2,1} & \cdots & t_{2,nd} & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ t_{nCG,1} & \cdots & t_{nCG,nd} & 0 & \cdots & 0 \\ 0 & \cdots & 0 & t_{1,1} & \cdots & t_{1,nd} \\ 0 & \cdots & 0 & t_{2,1} & \cdots & t_{2,nd} \\ \vdots & \cdots & \vdots & \vdots & \cdots & \vdots \\ \vdots & \cdots & \vdots & \vdots & \cdots & \vdots \\ 0 & \cdots & 0 & t_{nDG,1} & \cdots & t_{nDG,nd} \end{bmatrix} \quad (3)$$

where nCG is the number of conventional generators, nDG is the number of distributed generators. In the transaction matrix T, the ith row and jth column represents GenCos and loads; for example, $t_{1,1}$ represents generator 1 and load 1 (comma was added for clarity). Similarly the elements with distributed generators are represented (the lower right part). In general, the conventional load flow variables, generation (P_g^b) and load (P_d^b) vectors, are now expanded into two dimensional transaction matrix T as given in (4).

$$\begin{bmatrix} P_d^b \\ P_g^b \end{bmatrix} = \begin{bmatrix} T^T & 0 \\ 0 & T \end{bmatrix} \begin{bmatrix} u_g \\ u_d \end{bmatrix} \quad (4)$$

Vector u_g and u_d are column vectors of ones with the dimensions of n_g and n_d respectively. There are some intrinsic properties associated with this transaction matrix T [4]. These are column rule, row rule, range rule, and flow rule. These properties have been explained in [6]. Each contract has to range from zero to a maximum allowable value, T_{ij}^{max}. This maximum value is bounded by the value of corresponding P_{gi}^{max} or P_{dj} whichever is smaller. The range rule satisfies:

$$0 \le T_{ij} \le T_{ij}^{\max} \le \min\left(P_{gi}^{\max}, P_{dj}\right) \quad (5)$$

It is also possible for some contracts to be firm so that t_{ij}^0 is equal to t_{ij}^{max} [6]. According to flow rule the line flows of the network in AC model can be expressed as follows:

$$P_{line} = ACDF\left[P_g^b - P_d^b\right] \quad (6)$$

The AC distribution factors (*ACDFs*) are defined as the change in real power flow (ΔP_{ij}) in a transmission line-*k* connected between bus-*i* and bus-*j* due to unit change in the power injection (ΔP_n) at any bus-*n*. Mathematically, the *ACDF*s for line-*ij* can be written as:

$$ACDF_n^{ij} = \frac{\Delta P_{ij}}{\Delta P_n} \quad (7)$$

The matrix *ACDF* is the distribution factors matrix computed using AC load flow approach [13-14]. If the representations of the P_g^b and P_d^b are substituted by using the definition of T as given in (4), the line flows obtained for bilateral transactions with conventional and distributed generation can be expressed in an alternative as follows:

$$P_{line} = ACDF\left[T - T^T\right]\begin{bmatrix}1\\ \vdots \\ 1\end{bmatrix} \tag{8}$$

ACDF are based on Jacobian sensitivity matrix and includes any change in the system operating conditions.

4. Mathematical formulation for Secure Transaction Matrix Determination with Distributed Generation for Hybrid Electricity Market Model

The general problem formulation for determination of secure transaction matrix with AC distribution factors for hybrid market model can be represented as:

$$\text{Min } F(x,u,p) \tag{9}$$

Subject to

$$h(x,u,p) = 0 \tag{10}$$

$$g(x,u,p) \leq 0 \tag{11}$$

F is an objective function, which is subjected to power flow inequality constraints represented as g and all equality constraints represented as h. Vector x represents state variables, u represents control variables, and p represents fixed parameters.

A. Objective function

In this work, secure bilateral transactions have been determined with bilateral share of conventional generators and distributed generators respectively. First part of an objective function is the secure transaction determination with conventional generators participating in bilateral share. Second part of the objective function is determination of secure transactions with distributed generators participating in bilateral share.

An objective function is the minimization of deviations from the proposed transactions as:

$$\text{Min}\left\{\sum_{i}^{sb_{CG}}\sum_{j}^{bb_{CG}} b_{ij}^{CG}\left(T_{ij}^{CG} - T_{ijCG}^{0}\right)^2 + \sum_{i}^{sb_{DG}}\sum_{j}^{bb_{DG}} b_{ij}^{DG}\left(T_{ij}^{DG} - T_{ijDG}^{0}\right)^2\right\} \tag{12}$$

b_{ij}^{CG} and b_{ij}^{DG} is a weighting factor indicating the importance of a particular transaction for conventional and distributed generators which is taken corresponding to the different cases of conventional and distributed generation share in the present work, however, it can be any value for planning and operational studies.

B. Operating constraints

i) Equality constraints:

Power flow balance equations for real and reactive power:

$$P_i = P_{gi} - P_{di} = \sum_{j=1}^{N_b} V_i V_j \left[G_{ij}\cos(\delta_i - \delta_j) + B_{ij}\sin(\delta_i - \delta_j)\right] \forall\, i = 1,2,\ldots n_b \tag{13}$$

$$Q_i = Q_{gi} - Q_{di} = \sum_{j=1}^{N_b} V_i V_j \left[G_{ij}\sin(\delta_i - \delta_j) - B_{ij}\cos(\delta_i - \delta_j)\right] \forall\, i = 1,2,\ldots n_b \tag{14}$$

Power balance equations for demand and generation for bilateral transactions with conventional generators can be written as:

$$\mathbf{P}_{db}^{CG} = \sum_{i}^{sb_{CG}} T_{ij}^{CG}, \quad \mathbf{P}_{gb}^{CG} = \sum_{j}^{bb_{CG}} T_{ij}^{CG} \tag{15}$$

Power balance equations for demand and generation for bilateral transactions with distributed generators can be formulated as:

$$\mathbf{P}_{db}^{DG} = \sum_{i}^{sb_{DG}} T_{ij}^{DG}, \mathbf{P}_{gb}^{DG} = \sum_{j}^{bb_{DG}} T_{ij}^{DG} \tag{16}$$

Based on (15) and (16), the power balance equation for bilateral share of conventional generators and distributed generators is:

$$\mathbf{P}_{gb} = \mathbf{P}_{gb}^{CG} + \mathbf{P}_{gb}^{DG} \tag{17}$$

Knowing bilateral share and pool share, the power balance equation for net generation with pool and bilateral share of conventional and distributed generators can be written as:

$$\mathbf{P}_{g} = \mathbf{P}_{gp} + \mathbf{P}_{gb} \tag{18}$$

Similarly, the total bilateral demand can be written as the sum of vectors for demand share with conventional generators and distributed generators as:

$$\mathbf{P}_{db} = \mathbf{P}_{db}^{CG} + \mathbf{P}_{db}^{DG} \tag{19}$$

Knowing the pool demand and bilateral demand, the total demand balance equation can be written as sum of the vectors for pool demand as well as the bilateral demand. The equation can be expressed as:

$$\mathbf{P}_{\mathbf{d}} = \mathbf{P}_{dp} + \mathbf{P}_{db} \tag{20}$$

Power flow equations with bilateral share of conventional and distributed generators for hybrid market model can be determined using AC distribution factors. The power flow equation for conventional generators can be determined as:

$$\mathbf{P}_{fb}^{CG} = ACDF\,(\mathbf{P}_{gb}^{CG} - \mathbf{P}_{db}^{CG}) \tag{21}$$

Similarly, the real power flow equation with distributed generators bilateral share is given as:

$$\mathbf{P}_{fb}^{DG} = ACDF\,(\mathbf{P}_{gb}^{DG} - \mathbf{P}_{db}^{DG}) \tag{22}$$

Similarly, the real power flow equation for pool share is given as:

$$\mathbf{P}_{\mathbf{fp}} = ACDF\,(\mathbf{P}_{gp} - \mathbf{P}_{dp}) \tag{23}$$

The total power flow with pool share and bilateral transactions can be determined as:

$$\mathbf{P}_{\mathbf{f}} = \mathbf{P}_{fb}^{CG} + \mathbf{P}_{\mathbf{fb}}^{\mathbf{DG}} + \mathbf{P}_{\mathbf{fp}} \tag{24}$$

ii) Inequality constraints: Real and reactive power generation for generators:

$$\mathbf{P}_{g}^{\min} \le \mathbf{P}_{g} \le \mathbf{P}_{g}^{\max} \tag{25}$$

$$\mathbf{Q}_{g}^{\min} \le \mathbf{Q}_{g} \le \mathbf{Q}_{g}^{\max} \tag{26}$$

Bilateral Transaction matrix limit between seller bus-*i* and buyer bus *j* can be written as:

$$0 \le T_{ij}^{CG} \le T_{ij}^{CG\max} \tag{27}$$

$$0 \le T_{ij}^{DG} \le T_{ij}^{DG\max} \tag{28}$$

Limits on voltage magnitude and angle:

$$V_i^{\min} \leq V_i \leq V_i^{\max} \tag{29}$$

$$\delta_i^{\min} \leq \delta_i \leq \delta_i^{\max} \tag{30}$$

MVA power flow limit:

$$\left|\mathbf{S}_{ij}\right| \leq \mathbf{S}_{ij}^{\max} \tag{31}$$

Secure bilateral transaction matrix determination with conventional and distributed generators has been formulated as a non-linear minimization problem utilizing equations (12) to (31). The model has been developed in GAMS and solved using GAMS CONOPT solver 21.3 [24]. The necessary parameters have been determined in MATLAB and transferred to GAMS environment using interfacing link between MATLAB and GAMS for obtaining desired results [25].

5. Case Studies

The proposed algorithm has been applied on the IEEE RTS 24 bus system [26]. The elements of the transactions represent the bilateral contracts between i^{th} generator acting as seller bus and j^{th} load bus acting as a buyer bus. The pattern of secure bilateral transactions with conventional and distributed generators, generation share to pool and bilateral contracts, real power flow in the lines, and real and reactive power losses have been determined with different percentage of bilateral share. In this work, it has been assumed that 50% of the total demand is contracted through bilateral negotiations and rest of 50% demand is considered as a pool demand. It is also assumed that distributed generators are participating in bilateral contracts with different share out of the 50% of bilateral share. The results have been obtained considering different cases, which have been categorized as:

Case 1: Bilateral transactions having share in the ratio of 40%:10% of the total demand with conventional and distributed generators.

Case 2: Bilateral transactions having share in the ratio of 30%:20% of the total demand with conventional and distributed generators.

Case 3: Bilateral transactions having share in the ratio of 20%:30% of the total demand with conventional and distributed generators.

The value of transactions $T\ (i,j)$ represents the bilateral contracts between the i^{th} generator bus and j^{th} load bus in per unit. The bilateral transactions have been determined for all the cases. These patterns of bilateral transactions obtained for Case 1 with conventional generator and distributed generators are shown in Figs. 1 and 2. Secure bilateral transactions obtained with conventional generators (Fig. 1) are T(1,1)=0.4320, T(1,2)=0.3036, T(1,3)=0.2069, T(2,9)=0.1352, T(2,10)=0.2704, T(2,13)=0.30, T(2,15)=0.5335, T(2,19)=0.3639, T(7,13)=0.5361, T(7,14)=0.2544, T(7,15)=0.5863, t(13,14)=0.3329, T(13,18)=1.332, etc. Secure transactions obtained with distributed generators (Fig. 2) are T(13,6)=0.0.0675, T(13,8)=0.0675, T(13,10)=0.1354, T(7,14)=0.0999, T(7,18)=0.0675, T(18,15)=0.2870, T(18,16)=0.0659, T(18,18)=0.2287, etc. For Case 2, Secure bilateral transactions obtained with conventional generators (Fig. 3) are T(1,1)=0.3240, T(1,2)=0.2910, T(1,13)=0.3356, T(1,14)=0.3937T(2,3)=0.2340, T(3,3)=0.1021, T(7,9)=0.2108, T(7,10)=0.2059, T(13,18)=0.999, etc. Secure transactions obtained with distributed generators (Fig. 4) are T(13,1)=0.1832, T(13,4)=0.1153, T(13,14)=0.3508, T(15,3)=0.1707, T(16,15)=0.2429, T(18,15)=0.3487, etc. Similarly, the secure bilateral transactions obtained with conventional and distributed generators for Case

3 are shown in Figs. 5 and 6. These secure bilateral transactions obtained with conventional generators are T(1,1)=0.2160, T(1,2)=0.1940, T(1,3)=0.3095, T(2,8)=0.1536, T(2,10)=0.1950, T(2,13)=0.2650, T(2,15)=0.2370, T(7,5)=0.1271, T(7,8)=0.2185, T(7,9)=0.1950, T(7,13)=0.2650, T(7,15)=0.3970, T(13,14)=0.1356, T(13,18)=0.6323, etc. The secure transactions obtained with distributed generators (Fig. 6) are T(1,2)=0.1342, T(2,1)=0.0106, T(2,3)=0.0106, T(13,1)=0.2680, T(13,6)=0.3603, T(13,18)=0.9539, T(15,2)=0.0738, T(18,2)=0.0486, T(18,3)=0.4843, T(18,4)=0.1629, T918,5)=0.2018, T(18,13)=0.7378, T(18,14)=0.1218, T(18,16)=0.2709, T(21,14)=0.4311, T(21,19)=0.5855, T(22,15)=0.9148, etc.

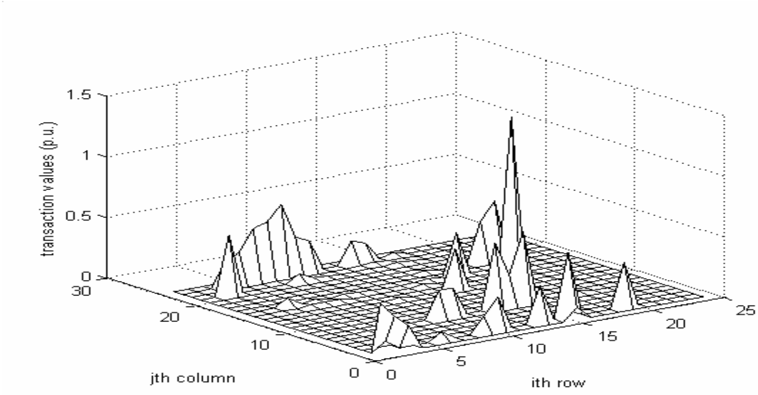

Fig.1. Pattern of bilateral transactions with share of conventional generators (Case 1)

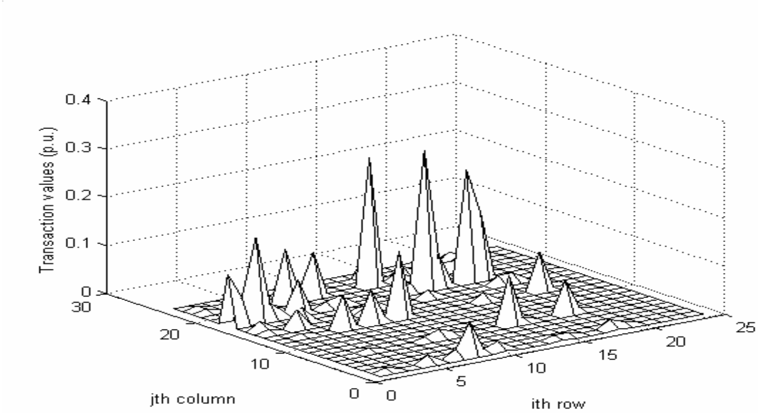

Fig.2. Pattern of bilateral transactions with share of distributed generators (Case 1)

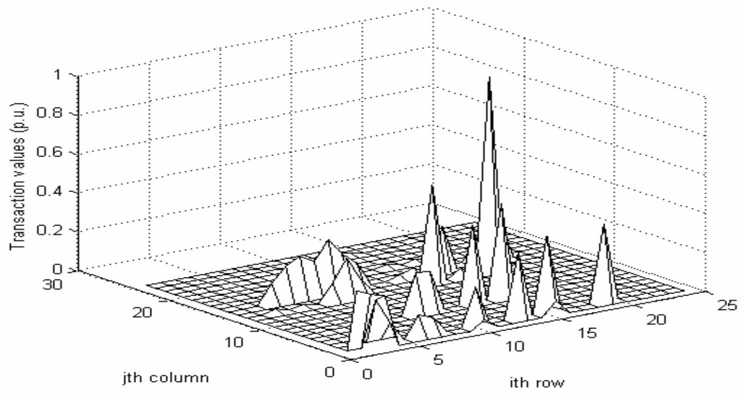

Fig.3. Pattern of bilateral transactions with share of conventional generators (Case 2)

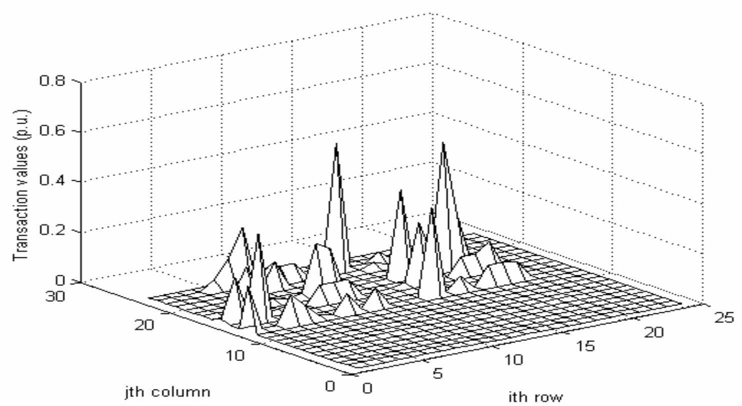

Fig.4. Pattern of bilateral transactions with share of distributed generators (Case 2)

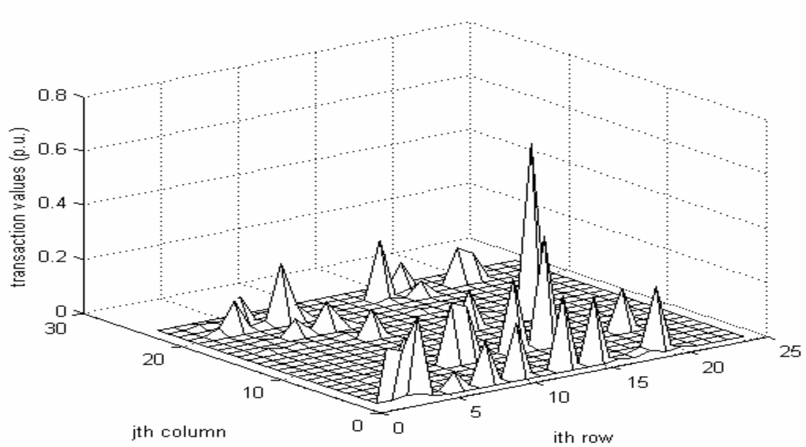

Fig.5. Pattern of bilateral transactions with share of conventional generators (Case3)

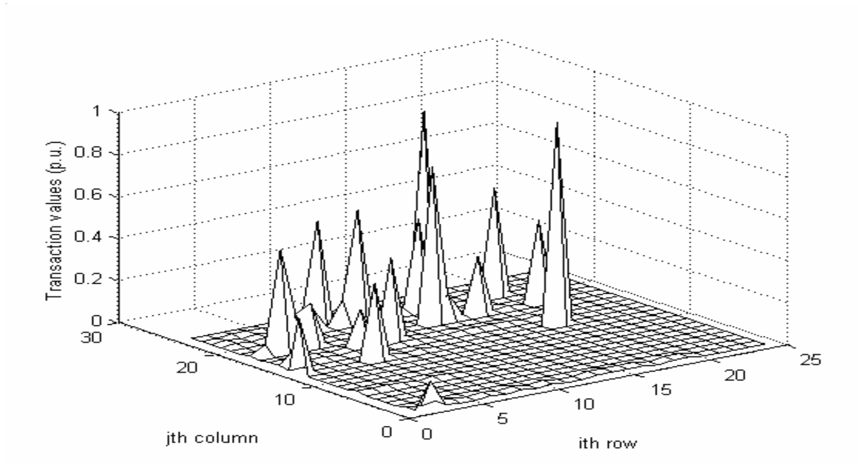

Fig.6. Pattern of bilateral transactions with share of distributed generators (Case 3)

The pattern of generation and load share for pool and bilateral demand with conventional and distributed generators for case 1 are shown in Figs. 7 and 8. Figure 7 shows the pattern of generation share for Case 1 having bilateral share with conventional and distributed generators. The pool generation and the total generation share are also shown in the figure. It is observed from the figure that the conventional generation share at buses 1, 2, 7, 13, and 16 is more than the share of DGs. However, the DG share at bus 18 is more then conventional generator. At bus 15, 16, 22 and 23 the DG share is quite small for bilateral transactions. Figure 8 shows the pattern of load share with conventional and distributed generators along with the pool demand share and total demand share.

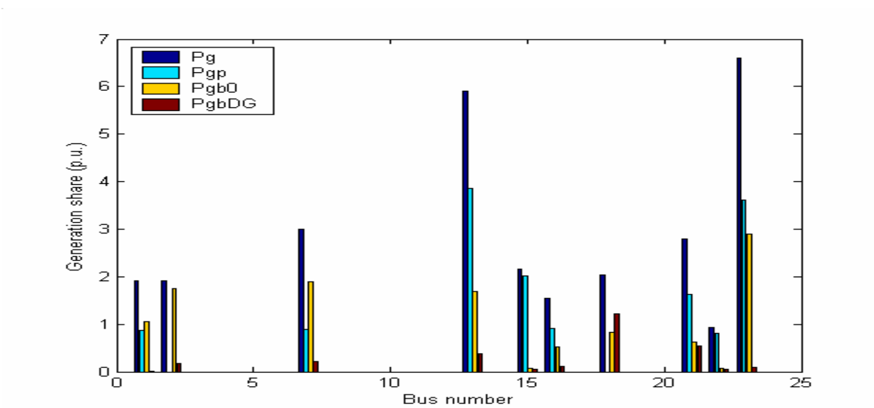

Fig.7. Pattern of generation share (Case 1)

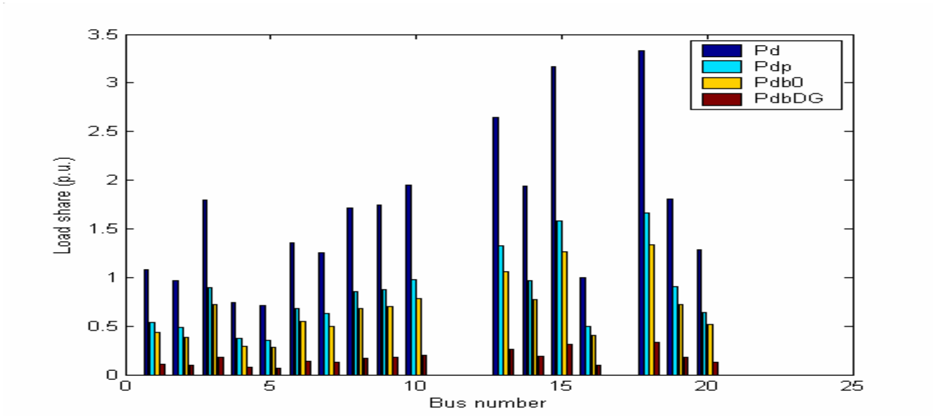

Fig.8. Pattern of load share (Case 1)

Similarly, the pattern of generation and load share for pool and bilateral demand with conventional and distributed generators for Case 2 and Case 3 are shown in Figs. 9 -12.

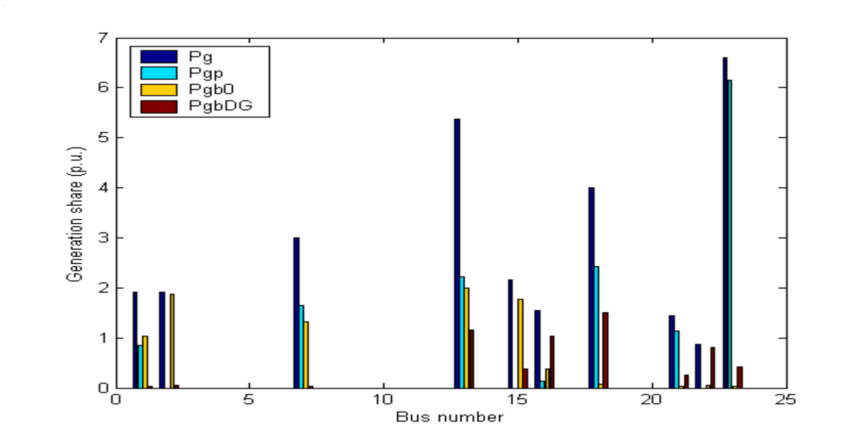

Fig.9. Pattern of generation share (Case 2)

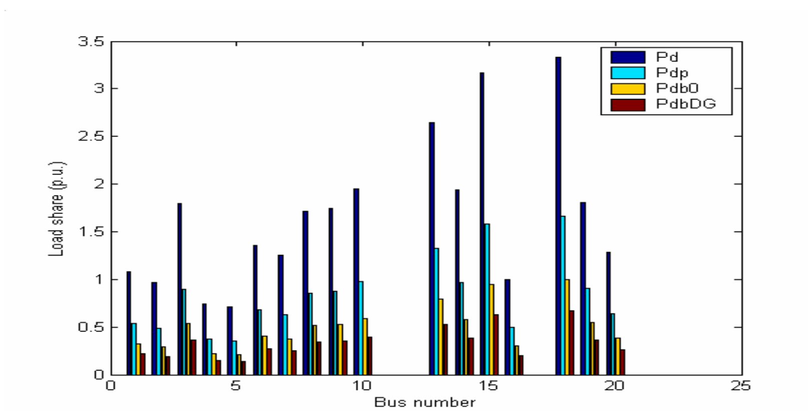

Fig.10. Pattern of load share (Case 2)

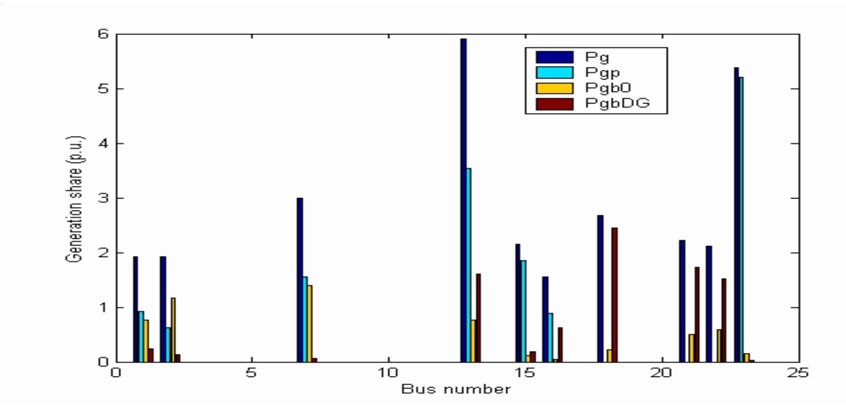

Fig.11. Pattern of generation share (Case 3)

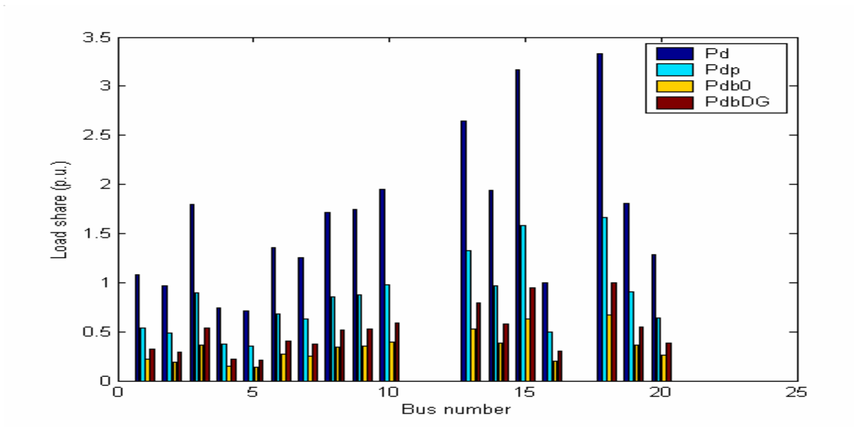

Fig.12. Pattern of load share (Case 3)

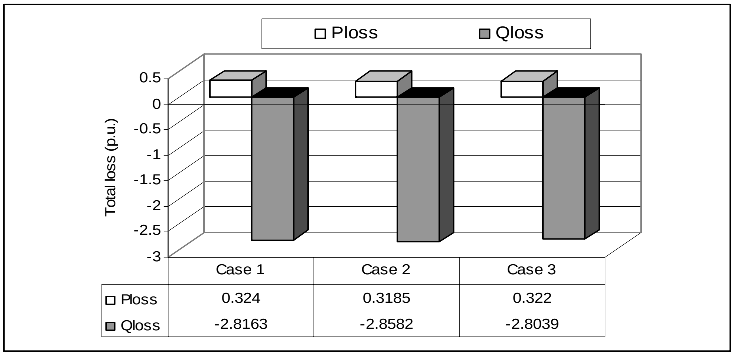

Fig. 13. Real and reactive power loss for all cases

Figure 9 shows the pattern of generation share for Case 2 having bilateral share with conventional and distributed generators. The pool generation and the total generation share are also shown in the figure. It is observed from the figure that conventional generators share more towards bilateral transactions at buses 2, 7, 13, and 15, however, DG share more at buses 16, 18, 21, 22 and 23. Figure 10 shows the pattern of load share with conventional and distributed generators along with the pool demand share and total demand share. Figure

11 shows the pattern of generation share for Case 3 having bilateral share with conventional and distributed generators. It is observed from the figure that conventional generators share more at buses 1, 2, 7 and 23 and DGs share more towards bilateral transactions at buses 13, 15, 16, 21, and 22. The pool generation and the total generation share are also shown in the figure. The total demand, pool demand, and demand share for conventional and distributed generators are shown in Fig. 12.

The real and reactive power loss for all the cases is shown in Fig. 13. It is observed that the real power loss reduces with distributed generation available and it increases slightly compared to Case 2 but is less than for Case 1. Thus with penetration of distributed generation with different bilateral share of generation, the real power loss in the system reduces. The reactive power follows the similar pattern. It is observed that for different conventional and distributed generation share in bilateral open access environment, different pattern of generation share for pool and bilateral demand are obtained. These patterns of generation and load share will provide information to the system operator for maintaining security of system along with the economic operation of generators participating in generation share to meet pool demand and bilateral demand with conventional and distributed sources available in the network. The complete scenario of patterns of generation, load, and transactions without and with distributed generation share will ensure the system operator to reserve remaining available generation in the system for its optimal use. The system operator having knowledge of additional capacity available in the network can post this information on a web site called “Open Access same Time Information System (OASIS)” for its further reservation as a commercial activity and optimal use of the system resources.

6. Conclusions

In this paper, a new approach has been presented to determine secure bilateral transactions in the presence of distributed generation available in the system. The model of transaction matrix has been modified with inclusion of distributed generators. The results have been obtained for different cases of distributed generation share in an open access bilateral environment. It is observed based on the results that different patterns of secure bilateral transactions are obtained for all cases. The patterns of generation and load share for pool, bilateral demand with conventional and distributed generators have been obtained for different cases. The real power loss decreases with increase in distributed generation share. These patterns of generation share, load share, and secure bilateral transactions will help system operator to maintain system security with the increased distributed generation share along with the conventional generators for better planning, operation and management of competitive electricity markets.

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